where

C = RF input power in dBm

F = receiver noise figure, dB

Δf = peak deviation of the channel for a 1 kHz test tone signal

f_{ch} = center frequency of the channel in the baseband

Similar equations apply to single channel FM voice and FM video, and to other modulation structures.

pW0p is one of many noise measures in use. Specifically,

dBrnc (dB above reference noise, C-message weighting. Reference noise is equivalent in power to a 1,000 hertz tone at -90 dBm.)

dBa (dB above reference noise-adjusted, F1A weighting. Reference noise adjusted is equivalent in power to a 1,000 hertz tone at -85 dBm.)

pWp (picowatts of noise power, psophometrically weighted.)

dBm0p (psophometrically weighted noise power in dB, with respect to a power level of 0 dBm.)

These units represent absolute values of noise. By appending a "0" to each (e.g., pW0p), the same units serve as measure of noise relative to 0 level signal (i.e., 0 dBm). Then the following approximate conversions apply (GTE-1972):

$$\text{dBrnc0} = 10 \log_{10} \text{pW0p} + 0.8 = \text{dBa0} + 6.8 = \text{dBm0p} + 90.8 = 88.3 - S/N$$

In general, most standards involve long term nominal objectives and short term or worst case threshold values. Below this threshold, an "outage" exists. FM links are often engineered so that the receiver FM threshold value of C/N is at or within a few dB of that value which gives the absolutely minimum acceptable performance. That is, the receiver RF performance threshold and the baseband (acceptable) performance threshold are matched.

As an example of a long-term performance objective, the latest CCIR position (reflected in Recommendation 353-3, CCIR-1978) is that 10,000 pW0p one-minute mean noise power should not be exceeded more than 20% of any month. The old U.S. criterion for long intertoll trunks required 20,000 pW0p or less nominal (in the absence of a fade). In the case of television signals, various criteria require a weighted baseband S/N of from 50 to 59 dB to exist under nominal conditions.

Noise performance requirements for small percentages can be thought of as "outage" conditions. The CCIR recommendation is that 1,000,000 pW0 (unweighted) measured with a 5 ms. integration time, exist not more than 0.01% of any year. An intermediate requirement is also established: that 50,000 pW0p one-minute mean power not be exceeded for more than 0.3% of any month. In the U.S., a criterion of 316,000 pW0p for .02% of the time is often employed. DCA standards similarly require that 316,000 pW0p not be exceeded for more than 2 minutes in any month nor for one minute in any hour. Video threshold requirements are typically in the 33 to 37 dB weighted signal to noise ratio range.

Criteria are under constant revision. Indeed, there are arguments suggesting that new applications require specialized criteria. Current criteria, developed for terrestrial systems or for satellite communications systems below 10 GHz, may not be applicable for millimeter wave systems where the statistics differ appreciably.

Note that outage criteria, such as the one DCA has promulgated (probability of outage on a five minute call), are very different from nominal or long-term availability criteria. Because propagation outages in the frequency range of interest typically have durations on the order of magnitude of minutes, it is not straightforward to relate availability statistics to outage probability statistics. Some approximations may be made from rain statistical data and limited data on fade depth vs. duration, but more theoretical and experimental work appears to be necessary before such outage criteria can be reliably applied in design. In this Handbook, therefore, we have found it necessary to emphasize availability criteria. Where duration data is available, it may be employed as a subsidiary, or second order, check on whether system requirements are met.

7.2.1.4 Summary of Nominal Criteria and Their Application

The nominal performance criteria for digital and analog systems are substantially different. However, these can be related by analysis to corresponding values of CNR, which communication engineers prefer to work with. There is, usually, a long term or nominal performance standard, as well as some definition of short term event behavior (outage criterion). With data systems, the long and short term phenomena may be statistically combined, so that it is possible to define combined performance criteria. These similarities, differences, and relationships are shown in Table 7.2-1.

Table 7.2-1. Performance Criteria and Relationships

System	Fundamental Quality Parameter	Nominal (Long Term) Performance	Short-Term (Outage) Criterion	Combined Criterion
Analog	Baseband noise or signal to noise	Mean or Median CNR	CNR equalled or exceeded except for p%	—
Digitized Analog	Baseband quality ⟷	Bit Error Rate ⟷ CNR	Same as above	—
Data	Error free block probability	Bit Error Rate ⟷ CNR	Outage probability	Error free block probability Throughput Delivery Delay

7.2.1.5 Additional Performance Criteria

In some applications, more specific control of the transmission quality is necessary and criteria such as those cited above are inadequate. In these situations a number of linear and nonlinear distortion parameters may be specified. Most of these relate to the system (hardware) components. It appears that the only significant distortion parameter introduced by the propagation path is phase fluctuation (scintillation)*. Small amounts can be accommodated in the power budget analysis as equivalent S/N or E_b/N_o degradations. (By "small amounts," we mean values which lead to no more than, say, 1 dB in equivalent S/N degradation.) On the other hand, large phase scintillations that occur infrequently will add to the outage time calculation, providing:

1) these events are not concurrent with the predominant cause of outage, namely amplitude fades (attenuation), and

2) the rate of phase variation is high enough that it will not be tracked by a digital system, or be filtered out in an analog system.

7.2.2 Recent Satellite Technology

The ever increasing demand for worldwide satellite telecommunication will saturate the available frequency spectrum allocated to current C-band and Ku-band services by the early 1990's. To meet future demands, the systems designer is exploring higher frequency bands (such as Ka) to relieve the congestion in orbit and developing new technologies enabling higher degrees of frequency reuse for a more efficient utilization of the orbital arc.

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*A possible exception is dispersion at frequencies near the absorption bands, but these bands will usually be avoided.

Most communications satellite designs include methods for frequency reuse. Polarization isolation is currently used on most C-band and Ku-band systems to effectively double the bandwidth and capacity of a satellite system. Another attractive method is to use multibeam (or spot beam) antennas, provided the beams are sufficiently separated to avoid beam-to-beam interference. Multibeam antennas are appropriate for satellite systems operating in the higher frequency bands because narrow spot beams can be achieved with moderate antenna sizes.

The principle of multibeam frequency reuse and its advanced technologies will enhance satellite capacity and orbital arc/spectrum utilization.

In satellite communication employing digital modulation, on-board processing (demodulation/remodulation) is becoming more widely used. Benefits include improved end-to-end bit error rate performance as well as improved terminal interconnectivity.

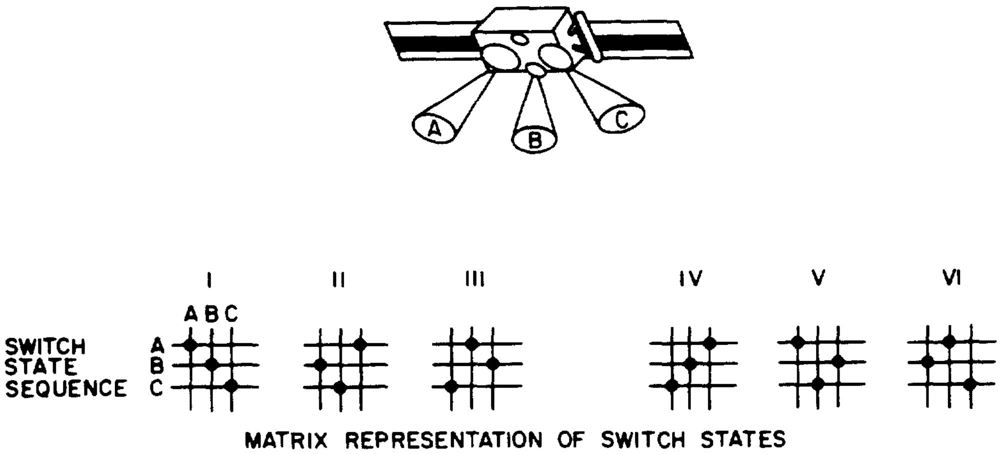
These relatively recent technologies are discussed in the following paragraphs. Section 7.3 discusses propagation considerations peculiar to the newer systems.

7.2.2.1 SS/TDMA

One way to increase the capacity of satellite comunication systems is to employ multiple beams with time division multiple access (TDMA) techniques. This is especially attractive at Ka-band since the higher the frequency, the more workable the multi-spot antennas are. However, this approach makes it difficult to ensure proper connectivity between uplink and downlink beams that cover different geographical locations. In order to reduce the number of required transponders, satellite-switched/time division multiple access (SS/TDMA) can be used.

In an SS/TDMA system the satellite uses several spot beam antennas and a microwave switch matrix (MSM) to route TDMA bursts arriving on different uplink beams to different downlink beams.

Figure 7.2-2 shows a simplified example of an SS/TDMA system that will be used for NASA's Advanced Communications Technology Satellite (ACTS).



	SWITCH STATE NUMBER	I	II	III	IV	V	VI
SWITCHING MODE ALLOCATION	FROM BEAM A	TO A	TO C	TO B	TO C	TO A	TO B
	FROM BEAM B	TO B	TO A	TO C	TO B	TO C	TO A
	FROM BEAM C	TO C	TO B	TO A	TO A	TO B	TO C

Figure 7.2-2. Diagram of the MSM interconnecting the three beams

The on-board Distribution Control Unit (DCU) programs the switch matrix to execute a cyclic set of switch states, each consisting of a set of connections between the uplink and down link beams, so that the traffic from various regions is routed to designated regions without conflict. A switch state sequence is a succession of switch states during a frame period. To accommodate all of the traffic presented to a system, a sequence of different switch states occurring in a periodic frame is required. For example, for complete interconnectivity between N beams, a total of N! different switch state sequences is needed.

The switching mode allocation describes both the succession and the duration of each switch state so as to route the desired amount of traffic among the beams. The first state shown at the bottom of Figure 7.2-2 provides the connections A to A, B to B, and C to C; the second state provides the connections A to C, B to A, and C to B, and so on.

Figure 7.2-3 illustrates a 3-beam SS/TDMA frame which consists of a synchronization field and a traffic field. The first state of the synchronization field provides loop-back connections to the origination beams. This provides for synchronization between the satellite switch and a TDMA reference station. The reference station in each beam observes synchronization errors of the stations in other beams and sends them necessary corrections. Subsequent states in the synchronization field provide for the distribution of reference bursts and location of synchronization bursts from the traffic stations. The traffic field consists of a number of switching modes and a growth space. The growth space is allocated to cope with traffic pattern changes, since unbalanced traffic between pairs of uplink and downlink beams are likely to occur. The satellite transponder utilization is maximum when the traffic field is fully occupied with a number of switching modes and the growth space is zero.

The Microwave Switch Matrix (MSM) is the key element of SS/TDMA system. ACTS MSM provides connectivity for the three stationary beams. The MSM is a solid state (dual-gate GaAs FET), programmable crossbar switch with a switching time of less than 100ns; it is a 4x4 IF switch, but only 3 input and 3 output ports are used at any given time (Naderi, Campanella - 1988). The INTELSAT VI satellite incorporates a 6x6 dynamic switch and a 8x8 static switch. The 6x6 switch provides interconnectivity between the two hemisphere beams, and the four overlaid zone beams, two in each hemisphere. The 8x8 static switch provides interconnectivity between the two 14/11 GHz spots and six 6/4 GHz beams. The static switch also provides

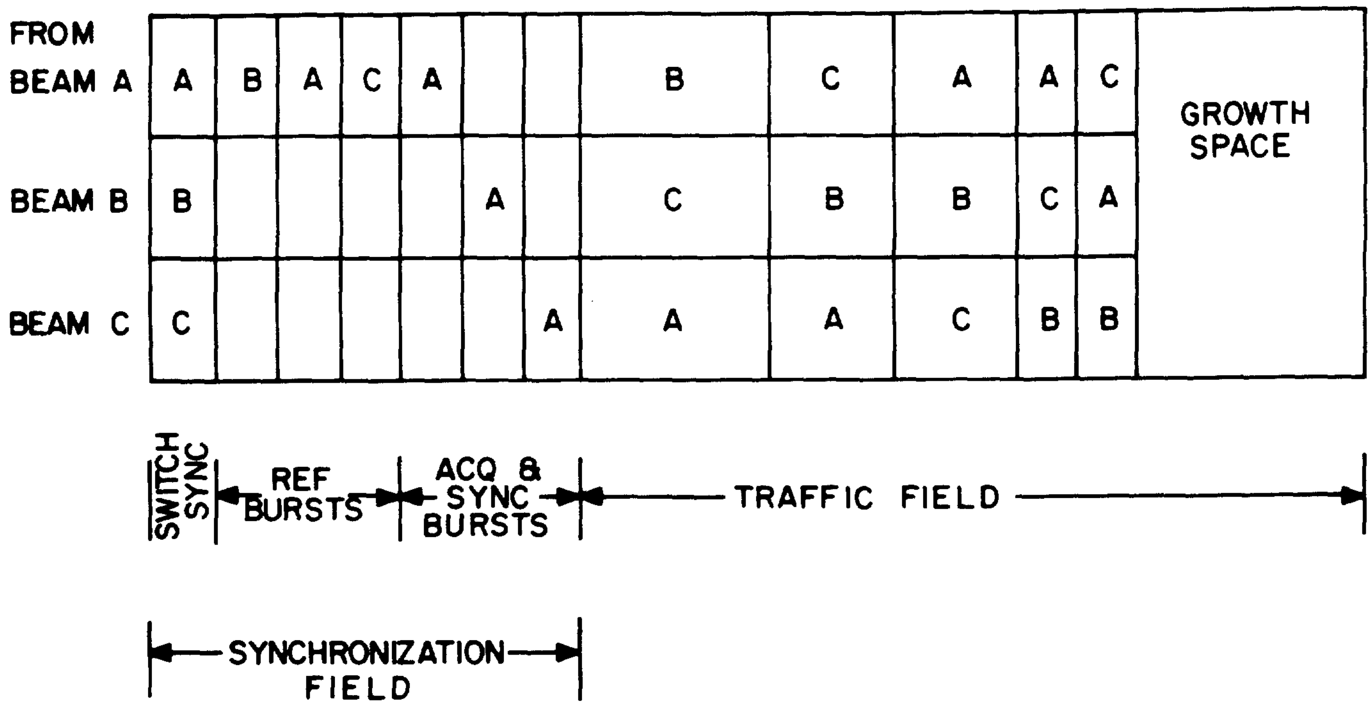


Figure 7.2-3. Typical SS/TDMA frame for a 3-beam system

interconnectivity between the two global beams (Scarcella and Abbott - 1983). The architecture the INTELSAT VI satellite switch matrix is a coupler crossbar with dual-gate GaAs FET switching elements.

7.2.2.2 On-board Processing

The difficulty with some of the more common means of satellite access, such as frequency division multiple access (FDMA) and code division multiple access (CDMA), is that the power in each of the downlink signals is controlled by the relative power in each of the satellite uplink signals. Thus, downlink power cannot be allocated to user requirements independent of the uplink. Furthermore, uplink power from each user must be carefully controlled to prevent saturation of the satellite power amplifier. Saturation distorts the signal modulation and generates undesired intermodulation products.

Time division multiple access (TDMA) to a satellite repeater avoids saturation of the power amplifier, but there is still an effective downlink power sharing (really, time sharing) problem because of the uplink time sharing. Moreover, linear and nonlinear distortion (intersymbol interference and AM-to-PM conversion) still occur because of required bandlimiting and amplification on the satellite. In addition, all users must operate at high data rates on both the uplink and downlink because of the burst transmissions.

On-board processing circumvents many of these difficulties first of all because uplink signal distortion and interference are not retransmitted on the downlink, and secondly because downlink power can be allocated in accordance with downlink user needs, independent of uplink transmissions. This allows interconnection of terminals that use different modulation and coding schemes. In addition, all downlink users will then have a common frequency standard and symbol clock on the satellite, which is useful for network synchronization.

On the other hand, on-board processing requires carrier and clock synchronization of the uplink signals, which functions are not required on a conventional frequency translation satellite.

To get an idea of the performance improvement achievable with on-board processing, Figure 7.2-4 shows a comparison between conventional and on-board processing satellites, in terms of uplink and downlink carrier/noise power ratios, considering a specified bit error rate of 10e-4. Ideal error rate (Pe = 1/2 erfc Eb/No) conditions are assumed, that is no degradation resulting from filtering or non-linear distortions.

Link analysis for an on-board processing satellite treats the uplink and downlink as two separate point-to-point analyses. To estimate the performance, it is necessary to determine separately the bit error probability on the uplink and downlink. The overall error rate is obtained by combining uplink and downlink error rates as follows:

$$BER_C = BER_U\,(1-BER_D) + BER_D(1-BER_U) \approx BER_U + BER_D \quad (7.2\text{-}3)$$

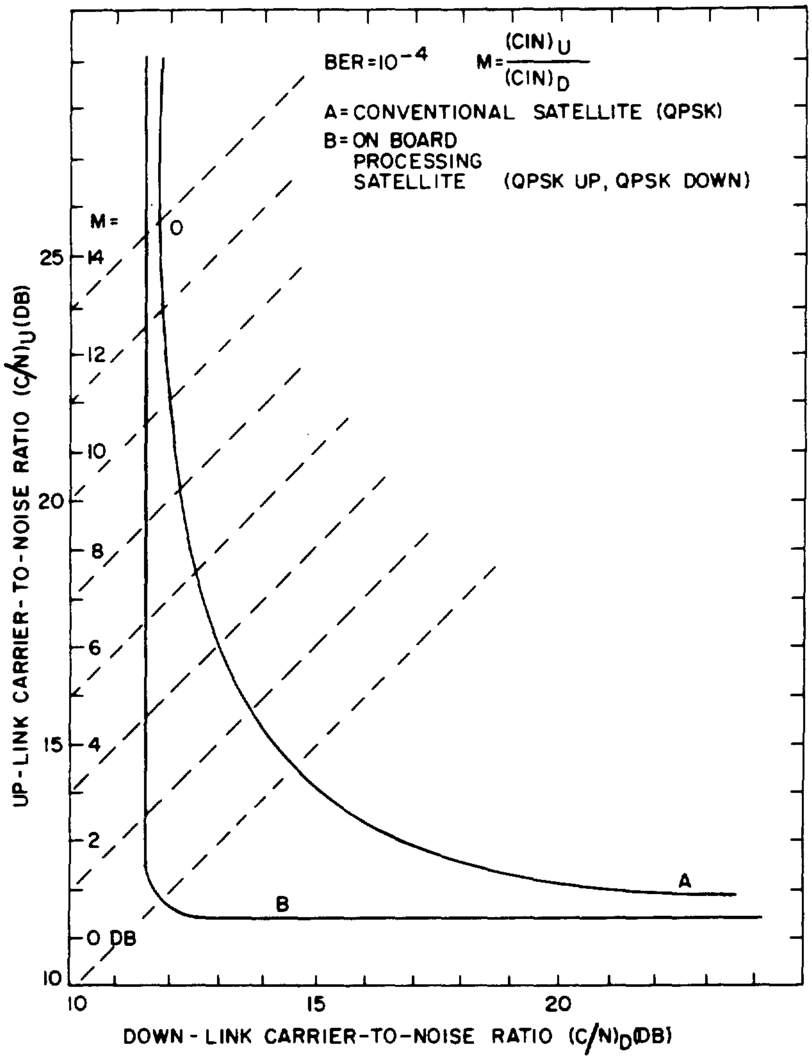


Figure 7.2-4. Comparison of conventional and processing satellite performances (linear channel)

By comparison, link analysis for a conventional satellite generally treats the entire "round-trip" (uplink transmission to the satellite and downlink retransmissions to an earth station) as a single analysis. To estimate performance, the uplink and downlink values of Eb/No (or C/N) are combined as follows:

$$(Eb/No)^{-1}_C = (Eb/No)^{-1}_U + (Eb/No)^{-1}_D \quad (7.2\text{-}4)$$

where the subscripts U, D, and C denote uplink, downlink and composite values respectively.

One can see from Figure 7.2-4 that the maximum power gain saving is obtained when uplink and downlink are the same. In that case the advantage of an on-board processing satellite compared with a conventional one is a saving of 3 dB on both uplink and downlink transmitted power. However, when the uplink power is much larger than the downlink power the saved power is much smaller (about 0.5 dB).

7.2.3 Representative Systems

Several systems that exploit expanded satellite capacity and efficient utilization of the orbital arc have recently been developed. These systems generally use higher carrier frequencies, such as Ka-band. This leads to the possibility of smaller earth stations, but at a cost of larger rain attenuation. Many of these systems use multiple beams, on-board processing and switching, and intersatellite links, as discussed in paragraph 7.2.2.

The proliferation of microterminals and VSAT systems provides a means for bypassing terrestrial communication networks. The Ku- and Ka-bands are particularly suitable for the VSAT application. Typical examples of current U.S. and European satellite communication systems are discussed in the following paragraphs.

7.2.3.1 VSAT Networks. The capability of satellite data communication networks has improved significantly because of recent advances in technology, especially in the area of microwave integrated circuits. This includes the development of solid-state power amplifiers (SSPA) with up to 5 watts of output power at C-band and 2 watts at Ku-band, low cost up-converters, and low noise down-converters. Current digital technology, which allows significant processing power in a small size and at low cost, led to the introduction of Very Small Aperture Terminal (VSAT) Networks for data communications.

VSAT networks are rapidly gaining in importance as a means of providing private voice and data communications for corporations that operate in widely dispersed sites. Currently two frequency bands are being used for VSAT networks: C-band and Ku-band. In general, VSAT networks operate at Ku-band because the higher frequency provides about 7 dB more gain than C-band for the same aperture size. On the other hand, Ku-band suffers significant rain attenuation, so consequently more system outages occur (Lyon-1985).

The networks are configured as hub-based systems, with a large earth station commonly referred as "hub," located at or near corporate headquarters and numerous small terminals (VSATs) located at remote sites. Since terminals are small, typically between 1.2 meters and 1.8 meters in diameter, it is usual to use a large earth station to receive and regenerate the transmitted data signals before distribution to other terminals. Hence, VSAT's communicate with the hub over the VSAT-to-hub satellite link and the hub station communicates with the VSAT usually by terrestrial links. Consequently, such communication involves double hops, which can present considerable difficulty for voice communication and is not used except in extreme cases.

With the use of a baseband processor on the satellite, the function of the major earth station can be replicated and the double hop eliminated. With this technology, voice communication would also be acceptable, because of the smaller time delays. This concept was recently proposed as an application of the NASA ACTS baseband processor technology (Naderi, Campenella-1988). The ACTS baseband processor will provide small customer premise services, allowing low data rate users direct and efficient access to the satellite. The use of spot beams and switching technologies will provide multiple voice channels to VSATs in a single satellite hop, neither of which is possible with current VSAT networks.

The range of possible applications for VSAT networks is widespread, particularly since rapid one-and two-way communications can be supported. Typical VSAT network applications include:

inventory management between retail stores and head-quarters, express mail and facsimile, travel and financial related services, meteorological data gathering, and corporate video distribution. Such variety in applications for VSAT technology is one force behind the growing number of companies installing VSAT networks to satisfy their ever increasing telecommunications needs. The emergence of these networks was stimulated by the U.S. industry investment in DBS-TV technology, the success of Equatorial Communications with over 25,000 receive-only and 1,000 transmit/receive VSATs installed, and the decision of Federal Express to purchase 50,000 small two-way earth stations for networking their field centers.

7.2.3.2 ACTS. The Advanced Communications Technology Satellite (ACTS), currently under development by NASA, will contain several new technologies and features which have the potential to dramatically enhance the capabilities of future satellite systems. ACTS will be one of the first satellites to operate a K_a-band (30 GHz uplink/20 GHz downlink), and will include electronically hopping multiple spot-beam antennas, on-board processing with baseband message routing, and adaptive rain fade compensation. These capabilities enable ACTS to provide multiple voice/data channels to VSAT type ground terminals in a single satellite hop, which is not possible with current VSAT networks at C- and Ku-bands (Naderi and Campanella-1988).

The ACTS system has two modes of access and operation:

1) On-board stored baseband switched TDMA, OSBS/TDMA, and

2) A SS/TDMA system based on IF switching, with no on-board processing. System access and control is accomplished by the network's master control station, located at NASA Lewis Research Center, in Cleveland, Ohio.

The OSBS/TDMA (on-board processor) mode demodulates and stores the received signal, reroutes data from input to output storage locations, then remodulates and transmits on the downlink beam.

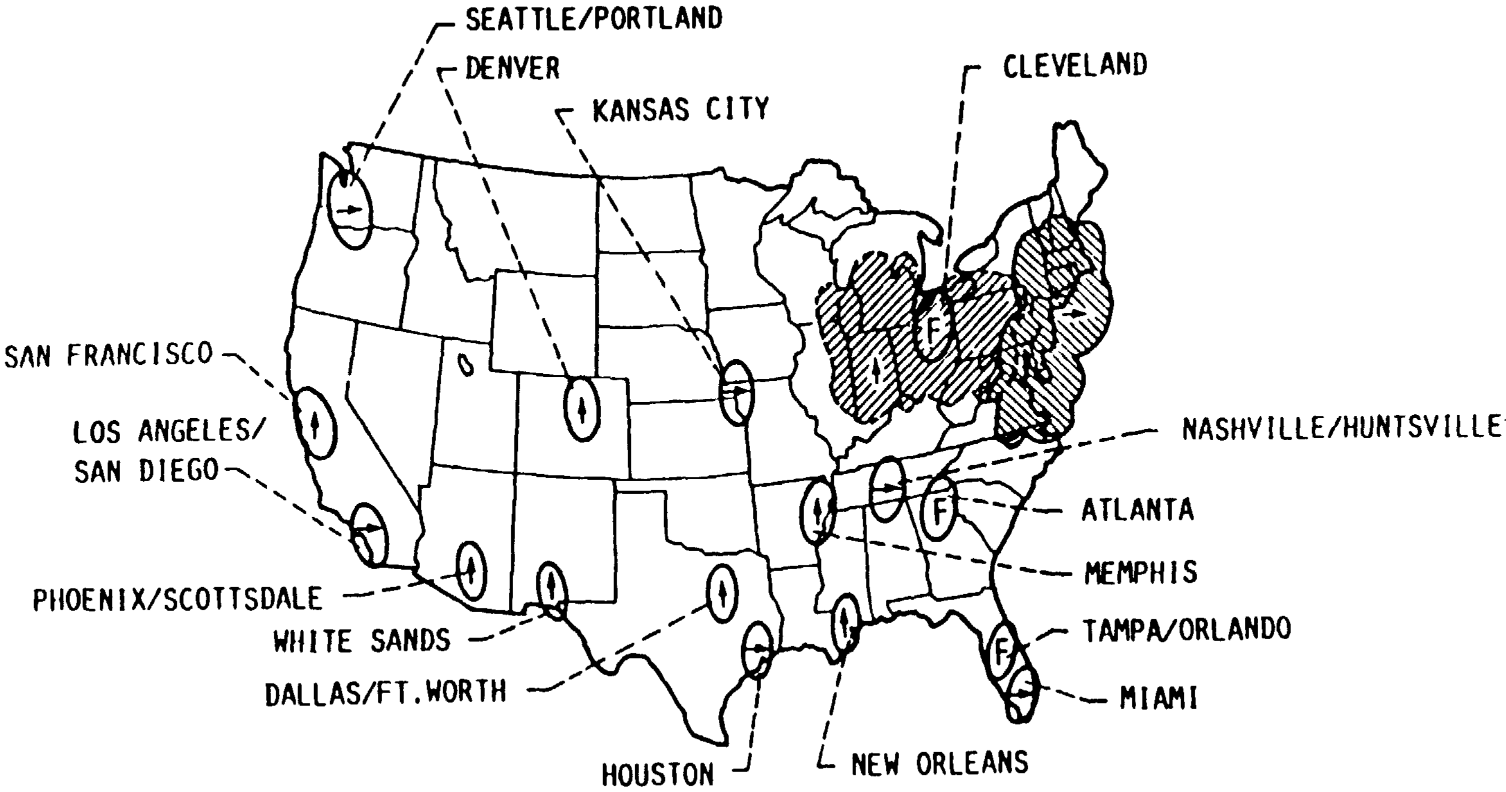
Serial minimum shift keying (SMSK) modulation is employed, with transmission rates of 110 or 27.5 Mbps on the uplink and 110 Mbps on the downlink

The SS/TDMA mode has no on-board storage or processing, other than switching. The system is designed to operate at a nominal burst rate of 220 Mbps, but other rates are possible. Since this mode is non-regenerative, ground terminals are not restricted in the modulation technique utilized for transmission.

Figure 7.2-5 shows the antenna beam coverage areas for ACTS. There are three fixed beams, focused on Cleveland, Atlanta, and Tampa, and two hopping beams. One of the hopping beams (vertically polarized) can hop to anywhere in the west sector (cross-hatched area on the figure indicated by a vertical arrow), or to any of the six fixed beam locations indicated by the vertical arrows. The second hopping beam (horizontally polarized) covers the east sector, and any of the seven fixed beam locations shown with horizontal arrows. A mechanically steerable antenna, not represented on the figure, is also included, which will provide a spot beam to anywhere in the disk of the earth as seen from the 100° West longitude location of ACTS.

Propagation measurements are an important element in the ACTS program, and will be accomplished both through the communications channels and with a set of three beacons available on the satellite. Table 7.2-2 summarizes the characteristics of the beacons on ACTS. The 27.5 GHz beacon and 20 GHz beacon pair operate through CONUS coverage antennas, providing a nominal E.I.R.P. of 13 dBw at edge of beam. The 27.5 GHz beacon is unmodulated, while <u>one</u> of the 20 GHz beacons will contain low rate telemetry data. The beacons will allow measurements of the classical propagation parameters, such as rain attenuation, depolarization, gaseous and cloud attenuation, diversity, and fade rate/duration.

Links operting in the OSBS/TDMA mode are desic ed for about a 5 dB clear weather margin, but terminals experiencing a fade can be



O SPOT BEAM
F FIXED BEAM
↑ POLARIZATION

ACTS AT 0° LATITUDE, 100° W
STEERABLE ANTENNA WILL COVER ALL OF U.S. INCLUDING ALASKA & HAWAII

Figure 7.2-5. ACTS Antenna Beam Coverage Areas

Table 7.2-2. ACTS Beacon Parameters

Item	27.5 GHz Beacon	20 GHz Beacons
Number of Beacons	1	2
Frequency (Polarization)	27.505 GHz ±0.5 MHz (Vertical)	20.185 GHz ±0.5 MHz (Vertical) 20.195 GHz ±0.5 MHz (Horizontal)
Modulation	None	FM and PCM (telemetry)
R.F. Power	20.0 dBm	23.0 dBm
Operating Temperature	-10 to +55 °C	
Frequency Stability	±10 PPM over 2 yrs at constant temperature ±1.5 PPM over 24 hrs for -10 to +55°C	
Output Power Stability	±1.0 dB over 24 hrs ±2.0 dB over full mission	

provided an additional 10 dB margin by a dynamic rain fade compensation method incorporated in the processor. Fade levels are monitored at the terminals either by the ACTS beacons, or by direct monitoring of the communications signal. Once a predetermined fade threshold is exceeded and the master control station is informed, two corrective actions are implimented; forward error correction (FEC) coding and burst rate reduction. Viterbi convolutional coding with a reduction of the burst rate to 1/2 is employed.

Fade compensation in the SS/TDMA mode is accomplished by a dual mode traveling wave tube amplifier (TWTA), which can operate with output powers of 11 or 46 watts. Locations undergoing a fade can be switched to the high power mode, resulting in over a 6 dB improvement in margin.

ACTS, scheduled for launch in 1992, will be used for a series of technology verification experiments over a period of two to four years. NASA has issued information on the requirements for participation as an experimenter with ACTS and has encouraged participation in a wide range of technology areas (NASA-1987).

7.2.3.3 INTELSAT VI The first commercial satellite, Intelsat I, initially known as the Early Bird, was launched in a geosynchronous orbit above the Atlantic in 1965, providing 240 two-way telephone circuits and one TV transatlantic channel. It weighed only 38 Kg in orbit and was spin stablized. Since 1965 over 100 commercial communications satellites have been launched to provide both domestic and international communications.

The latest addition to Intelsat's fleet of satellites will be the Intelsat VI. Intelsat VI is a dual-spin stabilized spacecraft, compatible for launch by either the Space Shuttle or Ariane IV. The major technological advancements of Intelsat VI include a sixfold reuse of the 6/4 GHz bands, the dynamic interconnection of six of the satellite's antenna beams for use with satellite-switched TDMA (paragraph 7.2.2.1), and a 10 year design life. The spacecraft provides a capacity of approximately 40,000 two-way telephone circuits plus two color-TV channels.

The antenna system consists of a 2 m diameter receive (6 GHz) and a 3.2 m diameter transmit (4 GHz) reflector; 1.12 m and 1.0 m diameter east and west spot beam steerable reflector antennas (14/11 GHz); and transmit and receive global horn antennas (6/4 GHz). The repeater system consists of 48 distinct transponders operating over the 6/4 GHz and 14/11 GHz bands. Frequency reuse through beam isolation and orthogonal polarization is employed at both frequency bands. The spacecraft thus has available a useful bandwidth of 3,200 MHz. Two 150 MHz, six 72 MHz, and two 77 MHz channels are assigned to 14/11 GHz. Twenty-six 72 MHz, two 41 MHz, and a maximum of ten 36 MHz channels are assigned to 6/4 GHz. Four of the 6/4 GHz, 36 MHz channels, as well as the two 41 MHz channels, provide permanent global coverage. Additional bandwidth of up to 72 MHz may be switched to global coverage. Finally, considering the availability of the hemi, zone, spot, and global coverages, up to 1,389 MHz of bandwidth can be assigned to earth stations in the geographic areas of highest traffic density (A. Ghais, and et. al., 1982).

The Intelsat VI provides static and dynamic interconnection capabilities to achieve the required signal paths from the receive to the transmit coverages. The spacecraft incorporates a 6x6 dynamic switch matrix which switches through a sequence of modes each frame and an 8x8 static switch which maintains a constant configuration for relatively long periods of time until changed by a new set of ground commands. The 6x6 dynamic switch provides full interconnectivity between two hemisphere beams and four overlaid zone beams. The 8x8 static switch provides full interconnectivity between the two 14/11 GHz spots, the six 6/4 GHz beams, and the two global beams.

The communications capability from Early Bird through Intelsat VI represents an increase in capacity by a factor of more than 150. The Intelsat system has maintained an amazing reliability factor of greater than 99.9 percent. Furthermore, it has achieved significant reduction in utilization charges.

7.2.3.4 <u>DoD Missions</u> The major role of the military in space activities today is for communication, navigation and observation. The Defense Satellite Communications Systems (DSCS) III and the Fleet Satellite Communication (FLTSATCOM) satellites are currently operational in worldwide military communications missions.

The DSCS III satellites consist of four synchronous satellites that provide reliable world wide communications to the United States defense forces throughout the 1980's and 1990's. Each three-axis stabilized satellite contains a Super High Frequency (SHF) communication payload consisting of multi-beam antennas and a six channel transponder designed for both FDMA and TDMA operation and real-time commandable uplink and downlink. By the early 1990's new payloads enhancing mission capabilities are feasible. Possibilities include advanced wideband user and AFSATCOM payloads. The new wideband payload features EHF links, adaptive nulling, on-board despreading, and an active transmit array giving higher capacity and jammer protection. The AFSATCOM payload includes EHF and UHF links plus multichannel digital demodulation to give higher jamming protection and capacity in a MILSTAR backup role and to provide EHF telemetry/commanding. Both payloads will utilize satellite crosslinks to improve global netting.

The Fleet Satellite Communications (FLTSATCOM) satellites are a powerful addition to the world-wide Navy, Air Force, and Department of Defense (DoD) network for communications between naval aircraft, surface ships, and submarines, ground stations, Strategic Air Command and the Presidential command networks. Each satellite provides twenty-three communication channels in the 240 to 400 MHz UHF band and at SHF. The communications transponder features channelized, limiting repeaters to facilitate access to low-power users and on-board processing for anti-jam protection. Four FLTSATCOM satellites are needed in geosynchronous orbit to provide visible-earth coverage for the DoD strategic and tactical users. FLTSATCOM 7 and 8 are modified with additional EHF transition packages to upgrade anti-jam protection. FLTSATCOM 6, 7, and 8 now provide world wide service until the early 1990's, at which time the new MILSTAR spacecraft will take over strategic and tactical service, both at UHF and at EHF.

The trend in DoD satellite communications systems, as with commercial and international systems, is to higher operational frequency bands. The EHF bands, (44 GHz up/20 GHz down), will see extensive service commence in the early 1990's, with MILSTAR, DSCS III, FLTSATCOM, and SDI (Strategic Defense Initiative) baseline communications elements.

7.2.3.5 OLYMPUS-1 Olympus-1, formerly known as L-SAT (Large Satellite), is an experimental 3-axis stabilized satellite being developed by the European Space Agency (ESA) for advanced satellite communications applications. It is a very large satellite, with a total span of 60 meters between solar panels, a transfer orbit mass of 2,300 kg, and a solar array power of 2.9 kW. Satellite location is at 19° W lattitude, with its control center at Fucino, Italy.

Olympus-1 consists of four separate payloads:

1) 12/20/30 GHz Propagation Package - for propagation measurements and experiments,

2) 14/12 GHz Specialized Services Payload - for business services experiments involving small customer premises earth terminals,

3) 17/12 GHz Direct Broadcast Satellite (DBS) Payload - for two channels of direct broadcasting services, and

4) 30/20 GHz Communications Payload - for point-to-point and multipoint communications applications.

Table 7.2-3 summarizes the characteristics of the Olympus-1 beacon package. All three beacons are coherently derived from a single frequency source. The 12.5 GHz beacon is transmitted through a full earth coverage antenna, which provides a signal to the entire earth sphere as observed from the satellite location. This provides coverage to all of Europe, South America and Africa, and to the east coast of North America. The 20 and 30 GHz beacons provide coverage through regional spot beams to Europe and North Africa only.

The 14/12 GHz Specialized Service Payload consists of four 30 watt transponders with an EIRP of 44 dBW. Each transponder can be subdivided into two TDMA data streams of 25 Mbps each, serving five spot beams covering most of Europe. Four of the five beams can be utilized in an IF switched SS/TDMA mode of operation.

The DBS Payload provides two channels, one for use by Italy, the other for the European Broadcasting Union (EBO). A 230 watt TWTA is employed, with a peak EIRP of 63 dBW available.

Table 7.2-3. OLYMPUS-1 Propagation Beacons

Frequency	12.502 GHz	19.770 GHz	29.656 GHz
Polarization	Vert.	Vert. or Hor. or switched (1866 Hz rate)	Vert.
EIRP (min.)	10 dBW	24 dBW	24 dBW
Frequency Stability:			
Over 24 hrs	±1.2 KHz	±2 KHz	±3 KHz
Over any 1 yr	±36 KHz	±60 KHz	±90 KHz
Over 7 yrs	±120 KHz	±200 KHz	±300 KHz
EIRP Stability:			
Over 1 sec	±0.05 dB		
Over 24 hrs	±0.5 dB		
Over any 1 yr	±1.0 dB		
Over 7 yrs	±2.0 dB		

The 30/20 GHz Payload consists of two 40 MHz transponders and one 700 MHz transponder operating through two independently steerable 0.6° spot beams. Each TWTA is 30 watts, resulting in an EIRP of 51 dBW for each of the spot beams. Videoconferencing, tele-education and wideband communications experiments, both point-to-point and multipoint, are planned.

Olympus-1 is scheduled for launch in 1989 on an Ariane launch vehicle, with an expected mission life of 5 to 10 years.

7.2.3.6 ITALSAT ITALSAT, the first satellite to be launched by the Italian Space Agency (ASI), is a wideband regenerative SS/TDMA system to be integrated into the existing Italian terrestrial telephone network, to improve performance and provide advanced access and routing techniques (Morelli, et al-1988). The satellite, to be located at 13° E latitude, is three-axis stabilized, with a payload mass of 255 kg, prime power of 1.565 Kw.

ITALSAT consists of three payloads:

1) 30/20 GHz Multibeam Payload - employing on-board baseband processing, for point-to-point and point-to-multipoint communications,

2) 30/20 GHz Global Payload - three non-regenerative transponders, for video and digital user services, and,

3) 20/40/50 GHz Propagation Beacon Package - for propagation measurements and experiments.

The multibeam package provides on-board demodulation at 12 GHz, and direct 4 phase QPSK remodulation at 20 GHz. The data rate is 147.5 Mbps, and the system operates with six 0.5° spot beams providing coverage throughout Italy and its islands. Six active repeaters provide a total capacity of 885 Mbps, equivalent to about 12,000 digital telephony circuits. 20 watt TWTA's are employed, resulting in an EIRP for each beam of 57 dBW.

The global payload consists of 3 frequency translation transponders, each with a 36 MHz useable bandwidth, operating through a single 1.8° x 1.3° beam. EIRP is 46.2 dBW, with 20 GHz TWTA's also employed.

Table 7.2-4 summarizes the characteristics of the ITALSAT propagation beacon package. All three beacons are generated from the same master oscillator. The 18.7 GHz beacon is used as a telemetry relay, and is radiated on the global antenna. The 40 GHz beacon is phase modulated at 505 MHz to provide two sidebands for differential attenuation and phase measurements over a 1.01 GHz bandwidth. The 50 GHz beacon is switched between polarizations at an 1866 Hz rate, similar to OLYMPUS-1, to measure cross-polarization characteristics. The 40 and 50 GHz beacons are radiated from 3° horns, to provide coverage over most of Europe.

Table 7.2-4. ITALSAT Propagation Beacons

Frequency	18.685 GHz	39.592 GHz	49.490 GHz
Polarization	Vert.	Vert.	Vert or Hor. or switched @ 1866 Hz rate
Modulation	PSK (512 bps)	PM (505 MHz)	None
EIRP (min)	23.7 dBW	27.8 dBW 24.8 dBW (mod.)	25 dBW
Frequency Stability: Over 24 hrs Over 5 yrs	 $\pm 3 \times 10^{-7}$ $\pm 3 \times 10^{-6}$		

The ITALSAT propagation measurements program is an ambitious effort involving a wide range of experiments and experimenters, and it will provide the first direct satellite path measurements at frequencies above 40 GHz (Giannone, et al-1986). ITALSAT is scheduled for launch in early 1991 on an Ariane 4 launch vehicle.

7.2.3.7 ATDRSS The current Tracking and Data Relay Satellite System (TDRSS) has for its main purpose the relaying of digital data from low-orbiting satellites to a single ground station, from where the data is distributed to the users that require it. The TDRS satellites themselves are geostationary bent-pipe satellites that will eventually replace the existing ground network of tracking and data relay stations. The Advanced TDRSS (ATDRSS) will upgrade the current system to satisfy user data relay requirements into the next century. This upgrade will include the capability of TDRS-to-TDRS crosslinks either at 60 GHz or at optical frequencies, together with the capability of relaying data directly to several ground stations, using K_A band links.

The capability of downlinking data to more than one ground station provides the opportunity to mitigate downlink rain fades by the use of site diversity (paragraph 7.4.2.1), thereby improving system availability. In addition, other fade mitigation techniques such as adaptive FEC coding (paragraph 7.4.3.2) are being investigated for use with ATDRSS. The goal is to achieve a 99.9 percent system availability. This will involve consideration of service scheduling (Schwartz and Schuchman-1982) that will allocate downlink power in accordance with user needs rather than simply the transmission of fixed power levels. Because of the multiple ground stations, on-board beam switching will be used for downlink data transmission, which, together with downlink power control, provides an opportunity for significant downlink rain fade mitigation (paragraph 7.4.3.1.2) not possible with the current TDRSS.

7.3 DESIGN PROCEDURE

7.3.1 Introduction

The procedure presented in this Section is a general one, applicable to satellite communication systems of conventional design and application. Special purpose systems, unusual variants, or unusual system architectures will require modifications to the procedure. For example, those systems which employ adaptive power control or adaptive antenna beam control fall into the "unusual" category. Power budgets for some of the newer satellite communication systems are presented at the end of this section.

The procedure is based on time percentage availability or outage as the primary and initial design criterion. Emphasis on this approach is necessitated by the fact that the largest amount of reliable propagation data is presented in time percentage terms. Where other criteria are important, different procedures may be necessary. But even where other criteria are employed, it is expedient to perform initial gross sizing calculations according to time percentage criteria.

As previously noted, the system design process is not a true synthesis. It consists rather of iterative analyses. The designer begins with some rough "guesstimates" of parameters such as earth terminal antenna size, satellite RF power, along with a set of system requirements (coverage area or locations, capacity, connectivity, and service criteria). By employing analytic (not synthetic) procedures, the designer determines whether the initial parameters and the requirements/criteria are consistent. If not, additional iterations are made, with adjustments either to the parameters or to the requirements. This last point is not trivial: if there is a large disparity between calculated system performance and the requirements, it may be necessary to consult with the source of the requirements and agree to a change (e.g., lower capacity or availability). The final system design parameters should always be verified in as many variables as possible according to available data. Thus, although the initial design may have been performed using an availability criterion, it may be of interest and importance to predict outage duration statistics, if the necessary data are available.

7.3.2 Path Performance Versus Overall Channel Performance:. Availability Allocation

The typical satellite communication application involves two or four distinct links. For example, a telephone trunk system between Los Angeles (LA) and New York (NY) will involve these links:.

LA to Satellite

Satellite to NY

NY to Satellite

Satellite to LA

If the performance requirements for this example specify the availability of a duplex telephone circuit between NY and LA, the system designer may be faced with a difficult problem. In general, finding the simplex, duplex, or (worst of all) system-wide availability with multiple earth terminal locations is a problem of considerable statistical complexity. Significantly, this problem is